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The Penn State Ballhead Cabbage

Some Problems Encountered In Its Development

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The Penn State Ballhead Cabbage

Some Problems Encountered In Its Development*

C. E. Myers†

WHEN the All-America Vegetable Awards for 1934 were announced in October 1933, the Penn State Ballhead cabbage was given national and international recognition.

It was the first variety of cabbage to receive this distinction. Previously and subsequently it has become widely distributed and favorably known. During 1941, the variety was listed by 76 per cent of the leading seedsmen of America. In 1933, when the last survey was made, this variety was grown extensively in Pennsylvania, New York, Connecticut, Massachusetts, Ohio, Michigan, Wisconsin, and Iowa, and to a less extent in Rhode Island, New Jersey, Virginia, Louisiana, Illinois, Minnesota, North Dakota, Nebraska, Colorado, California, and the Dominion of Canada. That year sufficient seed was sold to plant 4,000 acres.

DEVELOPMENT OF THE VARIETY

Since this is one of the few varieties of cabbage of commercial importance of which the complete history is known, it is believed that a record of the disappointments experienced and the manner in which they have been met with may prove helpful to those engaged in the production of this crop. Not all of the problems encountered have been completely solved, but the mention of them may lead to their study and probable solution by other workers more skilled or more resourceful.

INCIDENTS LEADING TO DEVELOPMENT OF VARIETY

The breeding work with cabbage at this institution is an outgrowth of strain tests initiated by Dean Emeritus R. L. Watts soon after he became head of the Department of Horticulture early in 1908. The writer was placed in charge of the work on July 1, of that year, and has been personally responsible for it to the present time.

The results of the strain tests are generally known and were reported in Bulletin 119 of the Agricultural Experiment Station and in the annual report for 1911 and 1912. They clearly demonstrated the important differences frequently encountered within a variety where the seed was obtained from different sources, and led to a better appreciation of the bearing of this fact on economic cabbage production. Figure 1 shows graphically the variation in yields of 31 different strains grown from 1909 to 1911 which were secured

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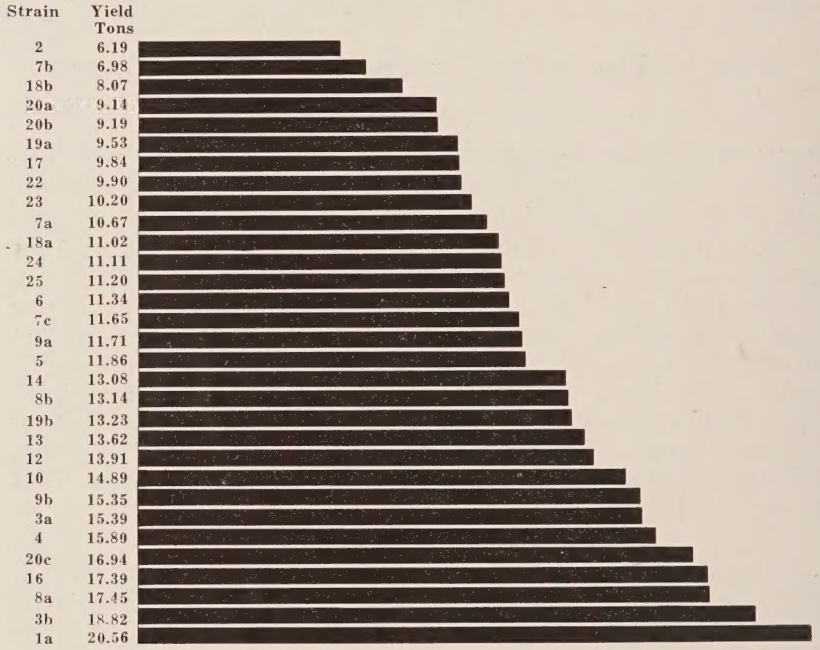

Fig. 1.—Variation in yield of 31 lots of Danish Ballhead cabbage secured from 25 different seedsmen. Average acre yield of tests for years 1909 to 1911 inclusive.

from 25 representative American seedsmen. It will be observed that the estimated acre yield ranged from 6.19 to 20.56 tons to the acre. The low yielding strain was designated by the seedsman who sold it as a "very choice strain", but it did not prove to be so when grown under central Pennsylvania conditions. In fact, none of the lots of this variety compared favorably with those of other varieties grown.

An experienced grower of cabbage suggested that perhaps the available strains of Danish Ballhead were not adapted to growing on a limestone soil, which is prevalent on the College farms, and suggested that selections be made of the best plants which appeared in the commercial strains with the thought of developing a strain or variety better adapted to these conditions.

As a means to this end, and in order to become better acquainted with the then present conditions of the cabbage seed problem, three lots of "stock seed" were secured from two of the leading seedsmen of the United States. These were planted the following year and were cared for in the same manner as were the plants of the

Fig. 2.—A single plant from "stock seed" of Danish Ballhead cabbage. Its very small head topped a spindly stem, in all about 26 inches tall.

general tests. The results were most unsatisfactory. That they could scarcely be considered worthy of the name "stock seed" is shown by the fact that of the 57 plants grown only 2 could be considered possible for seed production and these only with the greatest stretch of imagination. The general appearance of one lot is shown in figures 2 and 3. It will be observed that the stalks were very long, in one plant, 26 inches. The head of this plant was only

Fig. 3.—Three plants from another lot of "stock seed" of Danish Ballhead cabbage.

5 inches in diameter, and the outer leaves were placed loosely along the stalk. The photographs were made November 6, 1912.

In fact, neither of the so-called "stock seed" lots tested were superior to the ordinary seed secured from the same seedsmen and in some instances they were less desirable. Obviously, if a superior strain of Danish Ballhead was to be made available to cabbage growers, some conscientious work to that end was necessary. To prove or disprove that this could be done was the task before us.

SUMMARY OF DISAPPOINTMENTS AND SUCCESSES FROM 1912 TO 1941

A study of the 8 commercial strains, comprising more than 400 plants in the test of that year, showed some possibilities along these lines. Twenty-three mature plants were selected from these and five plants from a row of mixed breeding. These were placed in a trench about a foot deep in the ground and covered with soil, leaves, and boards, and finally with several more inches of soil. The plants wintered fairly well and when planting conditions were favorable the following spring they were transplanted. Fourteen plants matured seed which was harvested, on August 2, 1913, and kept separate. The following year a field planting was made with these seed stocks along with other trials, but because of the appearance of club root in the plot no record was kept nor were any plants retained for seed. This was disappointment number one.

The next year another planting was made of the seed from each of the 14 original plants. As the various lots approached maturity, it was observed that one, designated 111—, was particularly outstanding. On November 15, 1915, it was noted that the plants were of a superior type although the heads were more flat than typical Danish Ballhead. They were uniform and each of the 25 plants produced a marketable head. The lot was generally superior to any other grown that year or previous years on the College farms.

Eleven plants were selected for seed production the next year. Apparently, selection 111- gave promise of being the improved type which was being sought.

Perhaps the record of the results, by years, from that time to 1942 will prove interesting.

1916.—Of the 11 plants selected the previous fall, 9 survived and produced seed. A field planting of 200 plants was made of strain 111- on July 7. On October 25, it was noted that the plants were true to type and quite uniform, and that practically all would produce marketable heads. Nineteen were reserved for seed.

1917.—One hundred and eight plants of strain 111- were planted in the field on June 3. On November 5, they were recorded as being true to type and desirable. The yield was superior to any others in the test. Forty-six plants were reserved for seed.

1918.—On April 28, it was observed that 41 of the forty-six plants stored the preceding fall had survived the winter. These were planted in an isolated location and later approximately 1.3 pounds of seed were secured. The seed was saved separately from 19 plants.

The general field planting was made on July 17. It contained 54 plants of strain 111- along with 14 other strains of Danish Ballhead. Again it was found that strain 111- was the most uniform and desirable in the test and a number of plants were reserved for seed.

1919.—No planting was made for this year because of a leave of absence for the person in charge.

1920.—Nearly an acre was planted this year which consisted of the original 111- and 19 plant selections grown in 1918. A field planting was made on June 19. The results in general were very satisfactory, but some of the plant selections appeared to be more desirable than others. The estimated acre yield ranged from 22 to 34 tons to the acre.

The estimated acre yield is obtained by securing a random sample of each strain, that is, by cutting and weighing the head of every fourth plant, determining the average and multiplying by a

Fig. 4.—Comparative yields of a commercial strain of Danish Ballhead (left) and Selection 111-, (right) Nov. 2, 1920.

factor which gives the yield in tons to the acre. While this is not exact, it is a close approximation and is valuable for comparative studies and at the same time makes possible the reservation of many plants for seed production.

The average acre yield, based on 50 heads was 26 tons to the acre, while at the same time the acre yield from a commercial

Fig. 5.—Cabbage plants selected for seed production, Nov. 2, 1920.

Fig. 6.—The seed plants shown in figure 5 covered with approximately 3 feet of forest tree leaves.

strain, selected in the same manner, was 17 tons to the acre. These comparative yields are shown in figure 4. The results secured this year were very encouraging. Sixteen hundred and sixty-four plants were stored for seed production under leaves, according to a method recommended by a prominent cabbage seed grower. The appearance of the heads before and after covering with leaves is shown in figures 5 and 6. The results, however, were not satisfactory under State College conditions since only 504 plants survived and many of these did not mature seed. The condition

Fig. 7.—The appearance of the plants shown in figure 5 on March 25, 1921.

visioned on March 25, when the leaves were removed is shown in figure 7. In fact, only 1.66 pounds of seed were secured from the plants which survived; although many times this amount had been expected. Hopes for success had been severely shattered, but they were not destroyed. This was disappointment number two.

1921.—A field planting was made on July 5 and 6 of 16 plant selections representing 2540 plants. Illness prevented personal supervision of the work from July 6 to August, when it was found that an infestation of cabbage maggot had practically destroyed the plants so that no records were obtained and only three barrels of cabbage were harvested. The injury by maggot in previous years had been negligible. This may be considered as disappointment number three.

1922.—Seed of the parent selection of 111- and 10 of the best selections, as revealed by the test of 1920, were grown. This year,

Fig. 8.—Appearance of plants of No. 111-, Nov. 3, 1922.

as a result of the previous experience with cabbage maggots, the seed was sown in an enclosure covered with cheesecloth. At the time of planting the plants were dipped in a chemical solution consisting of one part bichloride of mercury to one thousand of water. Later these became infected with black-leg, *Phoma lignan*, and perhaps what was later identified as brown-rot, *Alternaria brassica*, and the results for the year were almost a total loss except that some of the substrains were less affected by the diseases than were others which is shown in figures 8 and 9. This may be considered as disappointment number four. Five hundred and thirty plants of the parent lot and selected strains were stored for seed. A more complete discussion of experiences with disease control will be given later.

1923.—The plants stored for seed the previous fall were transplanted on April 9. Five hundred and eighteen heads wintered very well and several pounds of seed were later obtained. On July 10, a field planting was made of the parent selection 111- and 11

Fig. 9.—General view of some substrains of No 111-, Nov. 3, 1922, showing apparent variability in susceptibility to black-leg and other diseases.

selections from it. Number 111- continued to maintain its superiority, but the others were also good. Three hundred and thirty plants were stored for seed.

1924.—The plants which had been stored the previous fall were transplanted on April 22. They wintered in splendid condition and nearly every plant survived. Twenty-five pounds of seed were obtained. The field planting consisted of 22 selections and other lots, comprising 2729 plants, and was made July 11. Black-leg and perhaps brown-rot were again quite severe during the season and disease was much more destructive to some lots than to others. The general type of plants which survived was good and 72 were reserved for seed.

Fig. 10.—Seed cabbage plants in bloom, May 21, 1926.

1925.—Fifty-eight of the 72 plants stored for seed survived the winter and were transplanted on April 18. A field planting was made on June 20, comprising 1 acre, and it consisted almost entirely of first and second generations of 111-. A total of 8407 plants was grown. The type was generally very good and the yield was satisfactory. Twenty-three hundred and thirty-two plants were stored for seed.

1926.—The plants stored the preceding fall were transplanted on April 30. Most of them had kept very well and 80 pounds of seed were harvested. Figures 10 and 11 show the appearance of the plants on May 21 and on August 5.

A field planting was made on June 26 of strain 111- and 30 selections, but because of very unfavorable conditions at the time of planting and subsequently, many plants were lost. Black-leg and perhaps brown-rot were again severe. Most of the plants that survived were true to type and desirable. Estimated acre yields ranged from 9.2 to 16.9 and averaged 13.26 tons for the 17 lots, but only a comparatively few plants were reserved for seed.

Fig. 11.—Seed cabbage plants nearly mature, Aug. 5, 1926.

1927.—Only thirty-one plants of those which were stored for seed survived and some of those did not mature seed. A total of 17 ounces of seed was secured from 8 selections. On June 28, strain 111- and 32 substrains were planted. The season was quite favorable. An acre planting of the same strains in another plot, matured 9677 heads which was 98.64 per cent of the number

planted. The actual yield was 23.76 tons. Four hundred and ninety-five plants were stored for seed.

1928.—Four hundred and nine plants survived the winter and were transplanted on May 7, and a good supply of seed was obtained. On July 2 a field planting was made of 50 selections and substrains. These showed a high degree of uniformity as will be seen in figure 12. Because of somewhat unfavorable conditions the

Fig. 12.—General appearance of four selections of No. 111-, Oct. 20, 1928.

yield was less than in some former years. The estimated acre yield for the season was 16.55 tons. Two hundred and eighty-two plants were trenched for seed.

1929.—On April 8, the trench was opened and it was found that 257 plants had survived the winter. Later 6.6 pounds of seed were harvested. On June 27, the field planting was made. It consisted of 83 selections and substrains. The season was somewhat unfavorable and black leg and perhaps brown-rot caused considerable damage. The estimated acre yield was 13.46 tons. Eight hundred and thirty-nine plants were stored for seed.

1930.—The plants stored the preceding year were transplanted from April 15 to 29. They had survived the winter quite well, but because of the delay in planting some of them, the yield of seed was considerably curtailed and only 6.1 pounds were obtained.

On June 21, the field planting was made of 115 plant selections and substrains. The injury due to diseases was severe and the estimated average acre yield of the various lots was only 6.94 tons. On November 6, seven hundred and eighty-five plants were stored for seed.

1931.—On April 22, the plants which had been stored for seed the previous fall were removed. Six hundred and eleven were trans-

planted and later 5.6 pounds of seed were harvested. The field planting was made on June 29 to July 1 on 2 different acre plots which consisted of 127 selections and substrains. Diseases were again present and materially affected the yield, but were much more severe on one plot than on the other. The average estimated yield of the various lots was 7.14 tons. On November 5, nine hundred and ninety-seven plants were stored for seed.

. 1932.—On April 26, the seed plants stored the preceding fall were transplanted. They had wintered poorly and the subsequent growth was unsatisfactory. Only 3.26 pounds of seed were secured.

The field planting was made from June 22 to 30. It consisted of 146 selections and substrains. The planting was made on two different locations on the College farm; one was on land not previously planted to cabbage. The season was more favorable than the preceding one, fig. 13. The estimated average acre yield of the selections was 14.34 tons. Twelve hundred and forty-seven plants were stored for seed on October 28.

1933.—On May 12, the plants stored the preceding fall were transplanted. Because of being held so long in storage they wintered poorly and due to unfavorable weather conditions, only a very few plants matured seed. Less than three-fourths of a pound of seed was secured for the season. The field planting was again made

Fig. 13.—General appearance of selection No. 111-, Oct. 26, 1932.

Fig. 14.—Appearance of Corl substrain (PL. 1-5-1 etc.), April 25, 1934.

at two different locations, and as before, many of the tests were duplicated. The test consisted of 175 substrains and plant selections, planted in rows of 35 plants each, and 247 plant selections of 10 plants each. The field planting was made from June 26 to 29. The season was quite favorable and the estimated average acre yield of all the row lots was 21.56 tons. On November 3 and 4, eleven hundred and twenty-three plants were stored for seed.

1934.—On April 23, the plants stored the preceding November were transplanted. All had wintered in excellent condition, and figure 14 shows one substrain. As the season advanced, however, soft rot and black-leg developed, and rains during the blooming period materially reduced the seed set which was below reasonable expectations.

The field planting was made on June 25, and consisted of 227 row tests of substrains and plant selections and 82 plant selections of 10 plants each. In general the season was good and the estimated average acre yield of the row test was 21.04 tons. On October 25 to 27, ten hundred and eighty plants were stored for seed.

1935.—On April 22 to 25, the trench was opened and it was found that the plants had wintered less favorably than the preceding year. Eight hundred and eighty-five plants survived and were

transplanted. The conditions were more favorable for seed production, however, and 8.77 pounds were secured.

The field planting was made on June 29. It consisted of 221 substrains and plant selections of 29 plants each and 26 plant selections of 10 plants each. The results were less favorable than those of the preceding year, and the estimated average acre yield for the row test was 13.72 tons. On October 28 to 30, ten hundred and nine plants were stored for seed.

1936.—On April 1, the trench in which the plants for seed had been stored the previous fall was opened. Nine hundred and nine plants had wintered quite well and were planted between April

Fig. 15.—Appearance of two selections of No. 111-, Oct. 31, 1936.

1 and 16. The season, for seed production, was quite favorable; 12.21 pounds were secured.

The field planting was made on June 29. It consisted of 221 substrains and plant selections in row tests of 25 plants each and 141 tests of 10 plants each. The season was favorable as will be seen in figure 15. The estimated average acre yield of the row test was 24.68 tons. On October 29 to 30, eleven hundred and twenty-three plants were stored for seed.

1937.—The plants stored for seed were examined on April 8, and were found to have kept very well. Eleven hundred and seven were planted from which 22.58 pounds of seed were later harvested.

The field planting was made July 6, on land that had not previously been planted to cabbage. It consisted of 247 substrains and plant lots in row tests of 28 plants each and 131 plant selections of 10 plants each. Conditions were less favorable than in the preceding year and the estimated average acre yield was 14.76 tons. On October 30, seven hundred and fifty-eight plants were selected and stored for seed in the trench. In addition 139 plants, representing 32 substrains and selections, were potted in 8-inch clay pots and placed in cold storage, to be later placed in the greenhouse for seed production, fig. 16. The securing of greenhouse space 28 by 25 feet for cabbage breeding work was the culmination of 23 years of efforts to this end.

1938.—On March 24, the plants trenched the preceding fall were transplanted. They had wintered very well, and 718 were planted in various places on the College farms. Later 13.79 pounds of seed were harvested. Thirty-nine of the 139 plants potted and placed in the greenhouse rotted and 15 did not seed. A part of all of the blossoms on each plant were bud pollinated and the seed obtained

Fig. 16.—Appearance of potted plants in the greenhouse, Jan. 10, 1938.

ranged from a few grains to 6 grams to a plant. Several crosses and sib crosses were also made.

The field planting, which was made June 30, consisted of row tests of 338 substrains and selections and 41 plant selections in 10-plant lots. These included 95 lots from bud pollination and crosses made in the greenhouse during the previous winter and spring months.

The season for growing was slightly more favorable than the preceding one and the estimated average yield of the various lots was 16.59 tons to the acre. Fifty-four lots were outstanding with respect to uniformity. They comprised 10 substrains and 9 plant selections of which 13 were from crosses produced in the greenhouse at the same time.

On October 31, fourteen hundred and twenty-five plants were trenched and 141, representing 66 selections, were potted, placed in cold storage, and later transferred to the greenhouse.

1939.—The plants stored the preceding fall were transplanted on May 2. Although they were held longer in storage than usual, because of unfavorable weather conditions, they wintered quite well and 1158 were transplanted. The subsequent conditions were not particularly favorable for seed production and only 8.73 pounds were secured.

Of the plants grown in the greenhouse, five succumbed to black-leg, six to soft rot, eight did not seed, and two were pollen sterile.

The field planting, which was made on July 7, consisted of 385 substrains, plant selections, and crosses, 102 lots of which were of seed produced in the greenhouse. Conditions for growth were less favorable than those of the preceding year, and the estimated average acre yield of all the tests was 13.37 tons. Eighty-eight lots were superior with respect to uniformity and of these 58 per cent were from seed produced in the greenhouse. Thirty-three plants were potted and placed in cold storage on October 16, and on November 2 and 3, thirteen hundred and two plants were placed in the trench and 181 were potted, placed in cold storage, and later transferred to the greenhouse. These consisted of thirty-one substrains and selections and 6 varieties of which 149 plants were from seed grown in the greenhouse and 32 from seed grown in isolated locations. The 33 plants placed in cold storage on October 16, were removed to the greenhouse on December 15. Diseases later developed and only six plants produced seed.

1940.—On January 3, the 181 potted plants which had been placed in cold storage on November 3, 1939, were transferred to the greenhouse. Later 93 developed diseases, mostly black-rot, brown-rot, soft rot, and black-leg. Six plants did not bloom but seed was

secured from the remaining plants in amounts varying from a few grains to several grams.

Evidently damage by disease in the greenhouse was becoming important. The manner in which it was controlled will be discussed later.

The plants which were trenched the preceding fall were not transplanted until May 6, because of the lateness of the season. Of the 1302 plants which were stored the preceding November, 1118 wintered well, and 63 were less promising. In general the season was quite satisfactory for seed production and 18.56 pounds were obtained.

The field planting was made on July 3 and 5. It consisted of 264 substrains and plant selections of which 165 were from individual plants which produced seed in the greenhouse and 99 were from plant selections which were produced by line breeding. The estimated average yield of the row test was 18.70 tons. Seventy-nine of the row tests were particularly outstanding with respect to uniformity and yield.

On October 31, eight hundred and eight plants were trenched for seed. Previous to this, on October 4, thirty-three plants of an earlier maturing strain were potted, and one very superior lot consisting of 72 plants was trenched in a private garden. On October 29, two hundred and seventy-three plants were potted, placed in cold storage and later placed in the greenhouse along with 33 plants which were potted on October 4.

1941.—The plants grown in the greenhouse did particularly well. Seed in varying amounts was secured from 225 plants and 52 crosses were made.

The plants trenched the preceding fall were removed April 18, having wintered especially well. In one lot of 496 plants only 1 rotted although 33 were destroyed by rats. Most of the other lots wintered equally well except the early maturing lot planted in the private garden which matured only a very small amount of seed. Due to unfavorable weather conditions during the blooming period, the seed crop was curtailed and only 5.62 pounds were secured from the other lots. Most of the seed produced in the greenhouse matured too late to be included in the field planting and will be reserved until 1942.

The field planting was made from July 1 to 3. It consisted of 146 substrains and plant selections which were planted in rows of 28 plants each or multiples thereof and 298 plant selections of 10 plants each. Of those planted, 96 were from seed produced in the greenhouse, mostly during the previous year. The conditions for growing were much better than those of the preceding year and

the estimated average acre yield was 23.76 tons. Forty-three row tests and 52 of the 10-plant lots were particularly outstanding with respect to uniformity and yield. These were used in larger plantings in 1942.

On October 29, seven hundred and ninety-eight plants were trenched for seed and 270 were potted in 9-inch clay pots and placed in cold storage. These were later transferred to the greenhouse for bud pollination and crossing.

DIFFICULTIES ENCOUNTERED IN THE PRODUCTION OF CABBAGE SEED

The cabbage plant is normally a biennial, that is, it takes two years to complete its life cycle from seed to seed. Because of this fact cabbage seed is much more difficult to produce than is the seed of many other crops and there are many things which may intervene before the life cycle is completed.

Previous to the last quarter of the nineteenth century, seed growing was largely a private family affair as were many of the other activities with which the individual family was concerned. Of course, some persons excelled in the production of certain commodities and these were exchanged for things which others produced. The same procedure prevailed in the production and distribution of seeds and particularly some vegetable seeds.

Possibly because the natural habitat of cabbage is along the sea coast, which provides a more uniform climate, the important seed production centers for this crop early developed, and still exist, in Denmark, Holland, France, Long Island, and in the Skagit Valley near Puget Sound. In fact, the belief has been expressed by some seed growers that nearness to salt water is necessary to pro-

Fig. 17.—Francis Brill and J. M. Lupton, Nov. 1, 1912.

Fig. 18.—Cabbage stored in trench and covered with boards laid flat, Nov., 1912.

duce good cabbage seed. The reason given is that the air is denser than inland and this in turn contributes to the development of plants with thicker leaves and more compact heads. The writer does not share this viewpoint.

Among the first commercial growers of cabbage seed on Long Island was Frances Brill who established a seed farm in Suffolk county, in 1870, where, as he states in a letter dated April 29, 1909, "Up to that time not a pound of seed of any description had been grown for market." Later C. L. Allen and also J. M. Lupton became prominent in cabbage seed production on Long Island. For many years the latter seedsman was a very extensive grower of this crop, fig. 17.

More recently much of the cabbage seed production in the United States has been shifted to the Puget Sound region, of which Mt. Vernon, Washington, is the center.

Early in this work a quite thorough search of literature was made to secure information concerning cabbage seed growing, but very little was found, although later a book by Reed *(11)* was help-

Fig. 19.—Appearance of cabbage seed plants which had been stored in artificial cold storage, April 9, 1923.

ful. Personal conversation with commercial growers of cabbage led to the first attempt to store the mature plants in a trench in the ground. The trench was approximately 8 inches deep and 2 feet wide. A pair of plants were laid at the end of the trench with the heads side by side; then a plant was laid with the head resting between the stems of the preceding lot. Two more were followed by one and this order was continued until all were placed and a stick was laid crosswise of the trench to separate the lots. The plants were covered with boards and these with soil, fig. 18. Fair results were obtained, but the method did not always prove reliable. Subsequently, storing under leaves, figs. 6 and 7 and also cold storage, fig. 19, were used, but results were not dependable. Finally, in 1932, the late Ernest Garrahan, a prominent market gardener of Kingston, Pa., suggested trenching the plants in soil,

Fig. 20.—Cabbage stored in trench and covered with boards, soil, and strawy manure, April 23, 1924.

Fig. 21.—The appearance of seed cabbage when trench was opened, April 23, 1924.

then covering these with boards placed "A" shape, placing over this approximately 6 inches of soil, and when the soil became frozen covering the whole with 12 to 16 inches inches of strawy manure. Later coverings of snow and manure were judged to be helpful.

These suggestions were followed and the results were highly satisfactory. Figures 20 and 21 show the appearance of the trench before and after opening the following spring. It will be observed that the plants wintered almost perfectly. Since then this method has been followed almost exclusively, with a few variations among which has been to extend the boards 6 to 8 feet beyond the end of the trench and to cover the opening with hardware cloth to provide ventilation and exclude rodents. As a further precaution against rats, shelled corn, soaked in strychnine solution has been scattered on the ground beneath the boards.

In some sections of America where cabbage seed is extensively grown, the general practice is to use immature plants, the heads of which are from one-fourth to one-third developed, fig. 22. This practice is conducive to production of seed much more economically than when mature plants are used since less labor is required and a greatly increased number of plants may be stored in a given space, but it does not make possible the careful selection which is necessary if seed is to be obtained which will produce plants possessed of a high degree of uniformity.

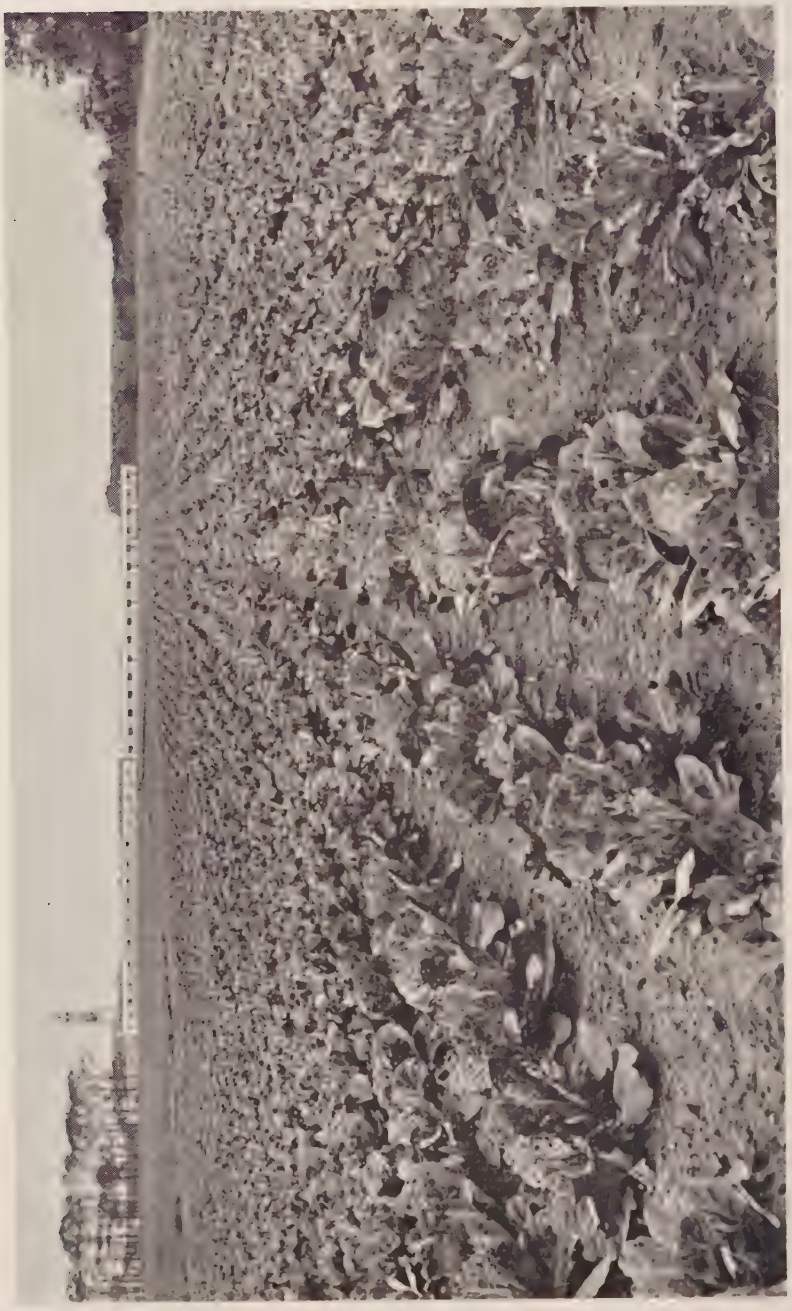

Fig. 22.—Ten acres of cabbage being grown for seed in Long Island, Nov. 1, 1912. Note immaturity of plants.

Two factors of utmost importance in successful cabbage seed production are to store the plants before they become injured by severe freezing weather and to transplant them in the spring as early at conditions will permit. Cabbage will stand temperatures of 25° to 20° Fahrenheit, depending on conditions, without injury, but repeated freezing and thawing will usually destroy them.

As already has been pointed out, cabbage is naturally a biennial. It seems that the plant requires a rest period before it enters the reproduction stage, although Melhus and associates *(8)* working with the Copenhagen Market variety did not find this necessary. Under natural conditions, this rest period takes place when the plants are stored in the manner previously recorded. Of course, if they are subjected to adverse conditions, usually low temperatures, in the immature stage, they may produce seed rather than heads. Henderson *(5)* cites an illustration of this, but the uncertainty of its happening eliminates it as a general practice in seed production.

The plants which have been stored are transplanted as early in the spring as conditions will permit. Under State College conditions plantings have been made as early as March 25. When planting can be made this early, and there is a possibility of low temperature later, it is well to set the plants rather deep in order that the stems may be fully protected by soil. Figures 23 and 24 show a selected lot of plants which were planted early and later partially covered with snow, but which eventually produced a good crop of seed. The plants are set in rows approximately 4 feet apart, the plants being spaced 3 feet in the row. An important procedure where plants with mature heads are used for seed production is to cut a cross in the top of the head. This will permit the seed stalk to develop normally. However, care must be taken not to cut too deeply, otherwise the terminal growth may be injured. Repeated cuttings may be made if necessary. It is also important to remove the head leaves soon after the plants have been transplanted. In a few days some will loosen and may be removed, and the process should be repeated as necessary. If this is not done, under central Pennsylvania conditions, a soft rot frequently develops which may attack the stem and cause a complete loss of the plant.

C. H. Myers and W. I. Fisher at Cornell University practice trimming the head to a block approximately 4 inches square. This method was modified in these experiments by making a circular cut with a long knife around the central stem leaving a core approximately $3\frac{1}{2}$ inches in diameter, fig. 34. Either of these methods tends to prevent the development of soft-rot.

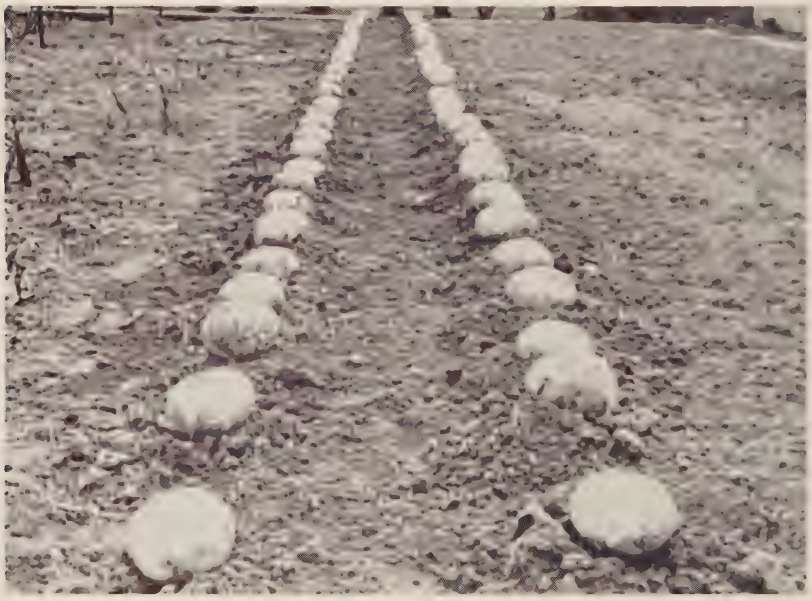

Fig. 23.—A selected lot of seed cabbage planted March 25, 1938. Note the depth to which the plants were set.

Fig. 24.—The same plants as in figure 23 partially covered with snow, April 10, 1938.

Cabbage is a naturally cross-pollinated plant. The flowers are quite large and the stamens and pistils are readily accessible which is conducive to wind and insect pollination, fig. 25. Because of this fact, all plants of varieties produced under normal conditions are heterozygous or complex individuals carrying seen and unseen characteristics which may appear in subsequent generations. Some of these characteristics are desirable and others are not, and it is the purpose of the plant breeder to control them to the end that a uniform product of the desired type may be produced at will.

Early in this work an attempt was made to inbreed outstanding plants by practicing self-pollination, since this procedure would tend to concentrate the genes responsible for the expression of certain visible characteristics. Many hundreds of blossoms were pollinated to this end, and although pollen was applied in abundance and the pistils appeared healthy and receptive, usually none or a very few grains of seed were obtained, fig. 26. When, however, mature pollen from a sister plant was used for pollinating, an abundance of seed was secured, as is shown in figure 27.

Since it was impossible to bring about the desired degree of inbreeding by self-pollination, another method was used as a partial means to that end. This was to save the seed from the plants separately, give each a pedigree number, and plant the plants in rows. Thus, plants most nearly approaching the ideal were chosen when mature, stored in a manner to retain their identity, which will be explained later, and planted when conditions

Fig. 25.—Cabbage flowers.

Fig. 26.—A cabbage plant which was repeatedly self-pollinated, but which produced very few seeds except when pollen from a sister plant was used. See branch to right of center.

were favorable in the spring in locations sufficiently isolated from each other that crossings would be reduced to the minimum. What this distance should be is largely guess work and is usually determined by physical conditions and the land available. In this work an effort was made to separate the lots at least one-third of a mile and further wherever practicable. The large lots were planted on the College farms. When there were selections consisting of only a few plants, arrangements were made to plant them in private gardens in different parts of the borough and in the surrounding country. One year it took a drive of 40 miles to care for these various lots. Honey bees, some solitary bees, and some species of flies are common insects which visit cabbage when it is in flower. How far they will fly is a matter of conjecture, although Taylor *(12)* notes that they sometimes fly as far as 10 miles for nectar, but 5 is usually their limit. For practical purposes it is necessary to separate the lots as far as possible, and if results of crossing later appear, these plants should be discarded. These can usually be determined quite readily as the plants approach maturity, es-

Fig. 27.—An enlarged view of the branch noted in figure 26. The blossoms between the tags were self-pollinated; those at the top were pollinated with pollen from a sister plant.

pecially if diverse types are being grown. Some crossing has been experienced of cabbage with sprouting broccoli, but the first generation plants may be readily identified as they approach maturity when they may be discarded.

The practice of line breeding in this manner contributed materially to the production of a more uniform strain, but because of the inherent heterozygous genetic constitution of cabbage the results were rather slowly realized.

If conditions are favorable at and following the transplanting of the seed plants they grow rapidly, and if diseases and insects are controlled, particularly soft-rot, black-rot and aphis, the plants will bloom the latter part of May, under State College conditions, and the seed will mature in late July. The practice has been to remove those branches containing seed as they mature. Before the pods open the bearing branches are collected in muslin bags and hung in a cool, airy place. When the pods are well dried the seed is removed by beating the bag containing them with a carpet beater. Later the seed is screened, immersed in hot water to control blackleg, and treated with bichloride of mercury to control seed-borne diseases of which black-rot is the most common. The seed lots are then placed in clean packages and correctly labeled, including field number and date.

EXPERIENCES IN CONTROLLING INSECTS AND DISEASES

Earlier in this discussion attention was called to the loss of a crop because of injury due to the cabbage maggot. This was overcome the following year by sowing the seed in well prepared soil in an inclosure which consisted of 12-inch boards, placed on edge to form a rectangle, over which cheese cloth was stretched after the seed was sown. Care was taken to place soil next to the lower edge of the boards and stretch the cheese cloth and fasten it in a manner to prevent the entrance of the flies which deposit the eggs from which the maggots develop. As a further precaution the plants were dipped in a bichloride of mercury solution, at the rate of one part to one thousand of water, when selected for planting. Since that time no further trouble with this insect has been experienced although the method of sowing the seed under cheese cloth has not been followed, but the bichloride treatment at the time of transplanting has been continued.

Various attempts have been made to control both the imported cabbage worm and the cabbage looper, but they were generally unsatisfactory until in 1941. At first arsenical sprays were used, and later dusts were applied in which arsenate of lead or calcium arsenate was the toxic ingredient. Hydrated lime was used as the carrier. The applications have been made with both single and double horse drawn dusters and with various types of hand dusters, but results were not fully satisfactory and considerable injury resulted. During the 1941 growing season a 1 per cent rotenone dust was used. It was applied by a 4-row duster drawn by a team. The first application was made when the white butterflies with two black spots on each wing, parents of the imported cabbage worm, and the yellow moths, parents of the cabbage looper, first appeared. This procedure was repeated at approximately weekly intervals throughout the season except when an examination of the plants showed that less frequent applications were sufficient. The results were generally satisfactory. Examination showed the presence of a very few plants which were quite heavily infected with the cabbage aphis. These were readily controlled by the use of rotenone dust applied by a hand operated duster.

The first disease which was troublesome was club-root which appeared in 1915. The land on which it was found was soon thereafter surrounded by a woven wire fence to prevent the disease being carried to other parts of the farm. In cooperation with the Department of Botany a rather comprehensive experiment was outlined and conducted for two years to determine the best method of control. Of the various treatments used, hydrated lime applied at the rate of 2 tons to the acre proved to be the most ef-

fective. Later the entire area inclosed was similarly treated and no further trouble resulted.

Previously attention has been called to experience with black-leg which was first recognized in 1922. Figures 8 and 9 show the injury caused and also the apparent differences in susceptibility of various substrains of Penn State Ballhead to the disease. For a time it was believed that seed of these showed a definite resistance, fig. 28, but further and more complete studies revealed the fallacy of this belief. This is well shown by fig. 29. Three rows were planted with plants grown from the same lot of seed. In the first row practically every plant produced a good head. The plants of the second row were considerably injured and those of the third row were much more so and practically every one succumbed to the disease. Many similar examples have been observed.

Since the idea of resistance proved to be erroneous, attempts were made to control the disease by other means. The first of these was to use various seed treatments. Accordingly, in 1928, a test was planned. The materials used were hot water, Chlorophol, Uspulun, Uspulun and Bayer Dust, Bayer Dust, and no treatment. The test lot consisted of 49 plants. Each treatment was repeated and hot water occurred three times in the test. At the end of the season, after the heads were cut, the plants were pulled and each was examined separately. The results are shown in table I. It will be observed that only one treatment, hot water, gave any

Fig. 28.—Three selections of Penn State Ballhead cabbage showing apparent variable susceptibility to black-leg, Nov. 5, 1924.

Fig. 29.—Three rows of cabbage grown from the same lot of seed showing varying amounts of infection by black-leg and other diseases, October, 1934.

promise, and apparently it was not very successful since only 7.6 per cent of the plants were free from injury which is well within the limits of experimental error.

It is generally accepted that differences less than 15 per cent are not statistically significant.

The next year a rather comprehensive experiment was outlined and instituted in cooperation with a representative of the Department of Botany. This was planned to determine the source of in-

Table 1.—Results of various treatments of cabbage seed applied in an effort to control black-leg.

Treatment	Number of Plants Planted	Condition of Plants at Harvest		
		Disease Free	Infected	Missing
Hot water	196	15	176	5
Chlorophol dust	98	0	97	1
Uspulun dust	98	0	94	4
Uspulun and Bayer dust	98	3	91	4
Bayer dust	98	0	94	4
No treatment	98	1	96	1

fection with respect to seed, seed beds, and field, and various seed treatments were used. The work was continued for two years, but no significant results were obtained and the work was discontinued.

The next attempt at control of black-leg was to continue operations on land which had not previously been planted to cabbage. This proved helpful, but land limitations made necessary the planting of cabbage on the same location at least once every four years. This practice led to an increasing intensity of damage by the disease before seed matured. Also plants which were placed in the greenhouse became badly infected and many died and did not produce seed. In 1940 a serious outbreak of disease caused by a species of *Alternaria*, probably *Alternaria brassica*, began to give trouble under storage conditions, and an attempt was made to control it. A member of the Department of Botany suggested a procedure which proved highly successful. First the seed was treated with hot water at a temperature of 50° centigrade (122° F) for 25 minutes, next it was cooled quickly in running water and immersed in

Fig. 30.—Washing seed cabbage plants with water from a hose previous to treatment and storing for the winter.

Fig. 31.—Dipping the plants in bichloride of mercury solution to destroy disease organisms.

bichloride of mercury solution, one part to one thousand of water (1 tablet to 1 pint of water) for 20 minutes, then it was washed in cold water and spread out to dry, and finally it was stored in new envelopes or containers. When a number of small lots were treated each was inclosed loosely in a cheese cloth bag and properly numbered to retain its identity.

The seed was sown and plantings were made on land which had not been planted to cabbage oftener than once in four years. Yet with this procedure some plants developed disease. Because of this, further precautions were taken when the plants were selected for seed. Any plants which showed the presence of the disease were discarded. The outer leaves were removed and the soil was washed from the roots by water from a hose, fig. 30. Next the roots and stems were dipped in a bichloride of mercury solution to destroy disease organisms which may have been present. Then the plants were placed in the trench, fig. 31. As a result of this procedure, in 1941 only 1 plant rotted of the 808 which were

Fig. 32.—Trench showing the method of placing the seed plants; the tape for measuring the distance of each lot from the beginning of the trench, and the boards nailed together in "A" shape ready for placing above the cabbage after soil has been scattered on the roots.

trenched on October 21, 1940. Each lot was identified by a numbered copper tag (aluminum will not do since it corrodes quickly) which was attached by a piece of copper wire to the stem of the last plant, a stick of wood being used to separate the lots from each other. Furthermore, the number of plants stored was recorded together with the location in the trench which was determined by measuring with a tape measure from the beginning of the trench, as will be observed in figure 32. This made possible the locating of any lot very readily when transplanting was done. Further treatment of the seed plants was according to previous discussion.

The plants which were potted for the greenhouse received the same treatment as those stored in the trench, except that the pots, and the soil for filling them, were sterilized with steam previous to the transplanting. This practice proved highly satisfactory in 1941

when of the 299 plants transferred to the greenhouse in January only 1 developed black-leg and 2 black-rot. This was an agreeable change from the preceding year when 93 of the 181 plants rotted during the early season of 1940. In a planting of approximately $1\frac{3}{4}$ acres in 1941, only 4 plants were observed to be injured by black-leg and 1 with black-rot.

Experience at the Station with cabbage yellows has been very limited. On July 11, 1934, two plants were observed to be infested in the general field planting. They were removed and burned, the soil in which they were grown was thoroughly soaked with a 10 per cent solution of formalin, and a barricade was placed to prevent persons from coming near the location.

At first, the presence of this disease was unaccountable for no infestation was known within many miles, and this was the first experience of the writer with it. A chance visit to the garden of a friend, a few days later, revealed its presence on some cabbage plants growing there, but its identity was not known by the owner. It happened that a boy from this home assisted in the field planting which was located approximately $1\frac{1}{4}$ miles distant. It is possible that he may have been the means of transmitting the disease. The year following one other infected plant was observed in the Station plantings and was treated in the manner already noted. Since then it has made no further appearance. When the disease was first observed in the test plots and it was found in State College, a partial survey of the home gardens of the borough was made and it was observed in 11 places and at several locations in the surrounding country. Thus far, the disease has not become serious in the vicinity of State College, but it has been troublesome in other sections of the state and there is need for developing a resistant strain of Penn State Ballhead. This is under consideration, but for the present active efforts to that end must be held in abeyance.

PRODUCTION OF CABBAGE SEED UNDER CONTROLLED CONDITIONS

During the past 25 years various attempts have been made to grow cabbage seed in the greenhouse by a number of research workers with varying degrees of success. Among these, Melhus *(8)* of Iowa was successful in setting plants of the Copenhagen Market variety in the greenhouse in October, 1918, and harvesting seed the following May. The plants were held at a temperature of 50° to 60°F. The heads formed in February and subsequently flowered without the intervention of a rest period. Detjen *(2)* also reported experience in producing seed in the greenhouse. His results were as follows: "In the fall of 1921, forty-seven seed plants were selected and placed in the cold greenhouse for seed production. They began to bloom on January 4, and the first seed ripened

on April 17. Twenty-eight plants tested for self-compatibility gave the following results: three have produced practically no seed at all notwithstanding the hundreds of flowers that were produced, less than 1 per cent of the buds set on these three plants; eight plants produced comparatively few and irregular plants; one plant produced a fair set of pods; three produced no pods; and only one plant produced very many or 100 per cent pods. Not one of the pods set in all of these cases was normal because each contained only a comparatively small number of seeds.

"The plants were hand pollinated practically every day during the blooming season. Other experiments strongly indicate that cabbage plants are strongly cross compatible, but only very weakly if at all self-compatible." He believed these characters to be inheritable.

Later Detjen *(3)* classified these characters into four distinct types. One year later Walker and others *(13)* reported their experience. They took mature plants and kept them in cold storage at a temperature from 50° to 60° F for several weeks in order to develop strong root systems before rapid growth of the tops took place. Then the temperature was raised to approximately 68° F. When the blossoms appeared they emasculated the buds before maturity so as to prevent selfing, and, by the use of a brush, pollinated every second or third day and secured a satisfactory set of seed. It is possible that the good results they secured were due to the use of mature pollen on some immature pistils. This procedure, which later was materially developed by others, was not recognized at the time. The pollinating was done in February and seed was secured in May.

Pearson *(10)* made an epoch-making discovery in cabbage breeding as a result of his study during the four years preceding 1929 when he showed that when mature pollen is applied, from one to five days before the blossoms would normally open, to an immature pistil an average set of 78.9 per cent of seed was obtained. The technique he practiced was "to insert the point of sterile forceps between the upper and lower sepals; when released, the forceps spread the sepals and exposed the stigma which was brushed with fresh pollen from protected flowers of the same plant." He also showed that the average number of seeds to the pod where the blossoms were pollinated when normally opening was 1.47 while flowers pollinated in the buds averaged 11.8 seeds to the pod. He likewise observed that there was considerable range between families in respect to the nature of the seed setting and suggested that it was probably due to the difference in hereditary constitution. He also suggested that there doubtless was a critical

time factor between the time of pollination and that when the sperm nuclei reached the ovules. Thus the older flowers, pollinated in the bud, which opened the day after pollen had been applied did not set seed since the ovules died before the sperm nuclei could reach them, while flowers that opened two days after pollination set seed in abundance. He believed that a condition exists in cabbage similar to that described in *Nicotiana* by East and Mangelsdorf *(4)* in 1926.

Kakizaki *(6)* in 1930 published the results of his studies on cabbage during the preceding six years. These closely parallel those of Detjen and of Pearson, but are much more comprehensive. He cited the work of East and Mangelsdorf and also that of others in which the hypothesis of multiple allelomorphs is used.

In his studies he relates a number of cases involving two varieties of cabbage, and among other things, concluded that "All the results obtained by the author are explained very satisfactorily by a new genetic hypothesis that two contradictory allelomorphic series, one oppositional S_1, S_2 and S_3 and the other sympathetic T_1 and T_2 affect the pollen-tube growth through the stylar tissue, and the S series is epistatic over the T series, but the T in double dose is more active than the S in simple dose". Furthermore, "Self- and cross-incompatibility in the cabbage is caused by the slow rate of pollen-tube growth. The slow rate of pollen-tube growth under incompatible pollination is due positively to the presence of a substance which inhibits the growth in the stylar tissue, and the normal growth of pollen tubes under compatible pollination is a result of either the absence of such an inhibiting substance or the presence of an accelerating substance which is able to prevent the inhibiting action."

"For the production of the inhibiting substance the S allelomorphs and for that of the accelerating one the T allelomorphs are respectively responsible."

"The inhibiting substance is produced most abundantly when the pistil is in its full vigor, and its production declines with the decline of vigor of the pistil. The pseudofertility in the case of bud-pollination of incompatible matings is very conspicuous in the cabbage. This is due mainly to insufficient inhibiting action owing to immaturity of the style, and also to the longer time duration at disposal for the growth of pollen tubes as well as the shorter distance to be traversed."

Fig. 33.—A few of the first plants placed in the new research greenhouse, Dec. 16, 1937.

In 1929, Miller *(9)* also made an epoch-making contribution to the science of cabbage seed production. Under the direction of H. C. Thompson, he made a comprehensive study of several important factors concerning seed stalk development. The student of the subject will want to study the publication carefully, but for the present probably the following will suffice: "The most effective method of hastening of seeding of those tried was storing the matured plants for two months at about 40° F and then growing where the temperature averaged 70° F. By this method seed was produced in less than one year from the time the seed was sown." The knowledge of this fact has placed research work on this crop on a firmer basis than ever before.

Fig. 34.—Seed plants in various stages of development in the greenhouse, Jan. 25, 1941.

Since 1937, when greenhouse facilities became available, these recently devised techniques have been used with a high degree of success. Figure 33 shows the appearance of the first plants which were planted in the greenhouse, December 16, 1937. Figure 34 shows seed plants in the greenhouse, January 25, 1941. Those in the foreground were treated with ethylene chlorhydrin at various concentrations and periods of time, but the plants did not produce seed any earlier than those in the background which were subjected to a temperature of from 35° to 40° F for 60 days, then 50° for 10 days to stimulate root development, and finally 70° for the remaining period. Note that the major portion of the heads have

Fig. 35.—The technique of bud-pollination of cabbage.

Fig. 36.—37. — Various stages of development of seed cabbage after being bud-pollinated.

Fig. 38.—A plant showing the effect of bloom in comparison with bud-pollination. No seed set on the left branch which was bloom pollinated.

been removed leaving only a cylinder of about 3½ to 4 inches in diameter from which the seed stalk emerges. This method eliminates the necessity of cutting the cross on the head and seems preferable to that method. As the seed stalk develops, some of the lateral buds are removed, thus confining the growth from five to ten major branches and sometimes less.

The method of bud pollination is not difficult, but becomes tedious when continued from day to day. As the plant blooms it is covered with a large glassine bag to prevent the dissemination of pollen from plant to plant. When the actual pollinating is being done, the plant is removed a distance from the others. After the buds have been opened with tweezers, a small camel's-hair brush is used to transfer the pollen from the mature blossom to the immature stigmas. The fingers of the operator, as well as instruments, are sterilized with alcohol after each plant has been worked. Figure 35 illustrates the details of the process of bud pollination and figures 36 and 37 show the results after different stages of development.

Frequently a plant has been permitted to develop only two main branches. One of these has been pollinated with mature pollen on mature pistils while the other has been bud pollinated. The purpose has been to secure, if possible, plants which

are normally self-fertilized. Although many attempts have been made very little progress has thus far been obtained. Figure 38 shows a plant which has been treated in this manner. The only pods which contained seed were on the branch to the right which was bud pollinated.

The general effect of inbreeding by line breeding, through isolating plants of a particular lot during seed production, or through bud pollination in the greenhouse, is to bring about uniformity of a particular selection, and the latter method attains this result much more quickly than the former. Figure 39 shows a strain of cabbage

Fig. 39.—The result of linebreeding for four generations. Note the general uniformity of the plants.

which was line bred for four generations while figure 40 shows similar results obtained by a year of bud pollination.

Within the last 10 years notable progress has been made in corn breeding and production as a result of the application of certain genetic principles. These are selfing individual plants for several generations and then crossing the inbred lines. Since cabbage is an open pollinated plant, similar to corn though probably less mixed, it was believed that crossing of inbred strains might lead to good results. In order to determine the validity of this opinion several crosses were made of inbred plants in the greenhouse during the winter of 1938-39. While it is possible that the results are not conclusive, they are of interest and support the hypothesis upon which they are founded. Figure 41 shows a first generation cross of two sister plants which were line-bred for three generations. The plants show a high degree of uniformity and the yield was significantly greater than that of either of the parents. Table 2 shows a

Fig. 40.—The result of bud-pollination for one generation. Note that this is practically as uniform as those of figure 39.

Fig. 41.—The result of crossing two sister cabbage plants which had been linebred for three generations.

comparison of head weights, yields and shape indices of five crosses and of one or both of the parents inbred from two to four generations. It will be observed that in every instance the yield of a cross was perceptibly greater than that of either parent. The average

Table 2.—Comparison of crosses and inbred parental strains of cabbage.

FIELD NO. IN 1938	FIELD NO. IN 1939	RECORD NUMBER	YEAR	PLACE OF CROSSING	HEAD WEIGHT	ACRE YIELD	SHAPE INDEX
					lb.	*tons*	
135-5 by		Pl. 201-5-5 ♀ by					
135-2	182	Pl. 201 XX-2 ♂	1938	Greenhouse	3.37	16.85	1.26
	171	Pl. 201-5-5 ♀	1938	Greenhouse	2.60	13.00	1.18
		Pl. 111-3-5-15-7-3 ♀ by					
310	291	Pl. 111-3-5-15-7-1 ♂	1938	Greenhouse	3.49	17.45	1.33
	286	Pl. 111-3-5-15 7-1 ♂	1938	Greenhouse	2.40	12.00	1.25
		Pl. 1-5-6-3 ♀ by					
	303	Pl. 1-5-6-5 ♂	1938	Greenhouse	4.51	22.55	1.41
	300	Pl. 1-5-6-3 ♀	1938	Greenhouse	2.71	13.56	1.24
	304	Pl. 1-5-6-5 ♂	1938	Greenhouse	2.73	13.65	1.39
		Pl. 153-4 ♀ by					
	344	Pl. 153-2 ♂	1938	Greenhouse	3.52	17.60	1.24
	341	Pl. 153-4 ♀	1938	Greenhouse	2.45	12.24	1.08
	337	Pl. 153-2 ♂	1938	Greenhouse	2.49	12.45	1.25
		Pl. 153-21-5-2 ♀ by					
	392	Pl. 153-21-5-1 ♂	1938	Greenhouse	3.75	18.75	1.30
	347	Pl. 153-21-5-2 ♀	1938	Greenhouse	3.03	15.15	1.22
	346	Pl. 153-21-5-1 ♂	1938	Greenhouse	3.24	16.20	1.20

difference in acre yield between the cross and the higher yielding parent was 5.8 tons. A study of these comparisons by "Students" Argument "t" as adapted by Love *(7)* gives odds of 249 to 1 that the difference is significant. Odds of 22.2 to 1 are generally accepted as being statistically significant.

Obviously the method of crossing in cabbage to bring about improved strains is, for the present, limited since the work must be done by hand. However, according to Roemer (cited by Pearson *(10)*), pollen of cabbage from another variety is much more efficient than from the same variety, and it is possible that a technique could be devised to bring about a considerable degree of crossing in the natural way. Furthermore, some tendency to male sterility has been observed by the writer and perhaps by others, and if satisfactory plant material containing this factor could be obtained it is probable that a practicable method could be devised which would meet commercial needs.

METHODS OF TESTING VARIOUS SELECTIONS AND SUBSTRAINS

In a breeding program where both type of plant and yield are factors of importance, a procedure is necessary which will enable the worker to determine and evaluate these in an acceptable manner.

Since the number of selections is easily and readily extended, it soon becomes necessary to adopt some system which will serve to eliminate the less desirable ones without the need of too much

Fig. 42.—Selection plant 153-, October, 1933.

detail, and then, having made the first selection, to use a method which makes possible reasonably accurate comparative tests.

Earlier in this work plant rows consisting of from 25 to 50 plants were used, depending on the number of lots to be tested and the land available. Rather complete notes were taken on each lot and comparative yields were determined. The increased number of lots concerned ultimately led to the development of a 10-plant test for preliminary observation, the lots selected as a result of this test being included in single or multiple row tests depending on the probable importance of the lot and the amount of seed available.

During the past season (1941) plantings consisted of 393 ten-plant tests and 140 row-tests of from 1 to 28 rows of 28 plants each. The 10-plant tests served to indicate those lots which promise to be of value and from which further studies should be made. An illustration of the 10-plant test is shown with substrain plant 153-. Its importance was first recognized when grown in a 10-plant test in 1933, when it was noted as being unusually uniform in color, head type, and maturity. Later it was placed in single and subsequently in multiple row tests which demonstrated its superiority in comparison with other lots grown at that time. It is now one of the most important substrains and more of it is planted than of any others. Figure 42 shows the appearance of the test in October, 1933,

Fig. 43.—Several rows of selections of plant 153-, October, 1941.

and figure 43 shows several rows of this selection in October, 1941, which yielded at the rate of 32.12 tons to the acre.

During the past season multiple row tests were conducted of five substrains in addition to the one previously mentioned. These were originally selected from the 10-plant lots because they appeared to possess some particular merit. Of these, yield, head weight, head shape, and uniformity are among the most important characteristics from the commercial standpoint. The results for 1941 are given in table 3.

Table 3.—Comparison of substrains of cabbage, 1941.

No. of Lots	Record Number		Head Weight	Acre Yield	Shape Index
64	153- etc.	Mean	4.83 ∓ .10	24.20 ∓ .53	1.29 ∓ .01
		S.D.	.82 ∓ .07	4.25 ∓ .37	.07 ∓ .01
		Coef. V.	16.97 ∓ 1.56%	17.56 ∓ 1.66%	5.42 ∓ .45%
15	19) etc.	Mean	5.12 ∓ .21	25.61 ∓ 1.07	1.28 ∓ .02
	20)	S.D.	.82 ∓ .14	4.15 ∓ .76	.07 ∓ .01
		Coef. V.	16.01 ∓ .30%	16.18 ∓ .30%	5.46 ∓ .92%
5	201 etc.	Mean	4.85 ∓ .02	24.28 ∓ 1.14	1.24 ∓ .02
		S.D.	.49 ∓ .01	2.55 ∓ .82	.06 ∓ .02
		Coef. V.	10.10 ∓ 3.23%	10.08 ∓ 3.23%	4.83 ∓ 1.60%
4	1-5-1 etc.	Mean	3.80 ∓ .15	18.87 ∓ . 76	1.20 ∓ .04
		S.D.	.30 ∓ .11	1.52 ∓ . 54	.07 ∓ .03
		Coef. V.	7.89 ∓ 2.88%	8.06 ∓ 2.88%	5.83 ∓ 2.15%
3	D12 etc.	Mean	4.18	20.88	1.24
2	111-3-5-15-7 etc.	Mean	3.33	16.65	1.27

In this table are shown the mean, standard deviation, and coefficient of variability with their respective standard errors for head weight, acre yield, and shape index. These statistical constants are valuable for comparison of the various substrains and to remove the personal factor when these comparisons are made.

For the benefit of those unfamiliar with these terms the following brief explanation may be helpful: Mean is the weighted average; standard deviation shows the tendency of the population to vary from the mean. Coefficient of variability shows the variability of the population from the mean in per cent. Standard error is a value — or + the given value which shows the limits within which the chances are approximately two out of three that the true value lies. It is due to a limited population.

Inspection of the first three substrains shows that there is no significant difference between these respective head weights nor is there in uniformity of head weight as shown by a comparison of the coefficient of variability, and the same is true with the mean shape index and also the uniformity of the same.

These values were determined by the formula $SE_D = \sqrt{E_1^2 + E_2^2}$ when the deviation divided by the standard error must be 2.2 to be significant.

A comparison of the fourth substrain with the three preceeding ones shows that it is different. For instance, the difference between the head weight of the first and of the fourth is 1.03 ∓ .18 which is, statistically, very significant. Also the difference of 9.08 ∓ 3.28 in the coefficient of variability shows the head weight of the fourth substrain to be more uniform than that of the first. Similarly, there is a significant difference between their acre yields and between their uniformity in this characteristic and a slight difference in the shape index, but not in its uniformity.

Thus the conclusion is justified that for the characteristics considered the first three substrains are essentially alike, but that the fourth is distinct in head weight and acre yield and in the uniformity of these characteristics.

The number of tests in the two last substrains were too small to make accurate comparisons possible, but are given as being probably representative of the respective substrains.

A study of a particular substrain for more than one year will probably be of interest. Table 4 shows this for the substrain, plant 153-, etc., from 1939 to 1941 inclusive.

Table 4.—Comparisons of the years 1939-41 of substrain plant 153-

NUMBER OF LOTS	YEAR		HEAD WEIGHT	ACRE YIELD	SHAPE INDEX
102	1939	Mean	2.62 ∓ .06	13.04 ∓ .31	1.28 ∓ .01
		S.D.	.63 ∓ .04	3.16 ∓ .26	.11 ∓ .01
		Coef. V.	23.66 ∓ 1.79%	23.67 ∓ 1.79%	8.59 ∓ .65%
39	1940	Mean	3.86 ∓ .10	19.14 ∓ .50	1.31 ∓ .14
		S.D.	.63 ∓ .07	3.15 ∓ .36	.90 ∓ .10
		Coef. V.	16.32 ∓ 3.03%	16.45 ∓ 3.03%	6.87 ∓ .81%
64	1941	Mean	4.85 ∓ .10	25.61 ∓ 1.07	1.28 ∓ .01
		S.D.	.82 ∓ .07	4.15 ∓ .76	.07 ∓ .01
		Coef. V.	16.97 ∓ 1.56%	16.18 ∓ .30%	5.46 ∓ .92%

A casual examination of the above table shows that there is a marked difference in the mean head weight and acre yield for each of the three years and in the case of the yield, that for 1941 is nearly twice that of 1939. There is also a material difference in the weight of heads for the three years, but no significant difference in the shape index. This is to be expected since the first two characters readily respond to various environmental factors while that of shape of head does not. The table clearly emphasizes the futility of drawing conclusions from a test of a single year. Three years should be the minimum and perhaps more would be desirable.

When Penn State Ballhead was first introduced some objection was raised because of the head being flatter than other strains

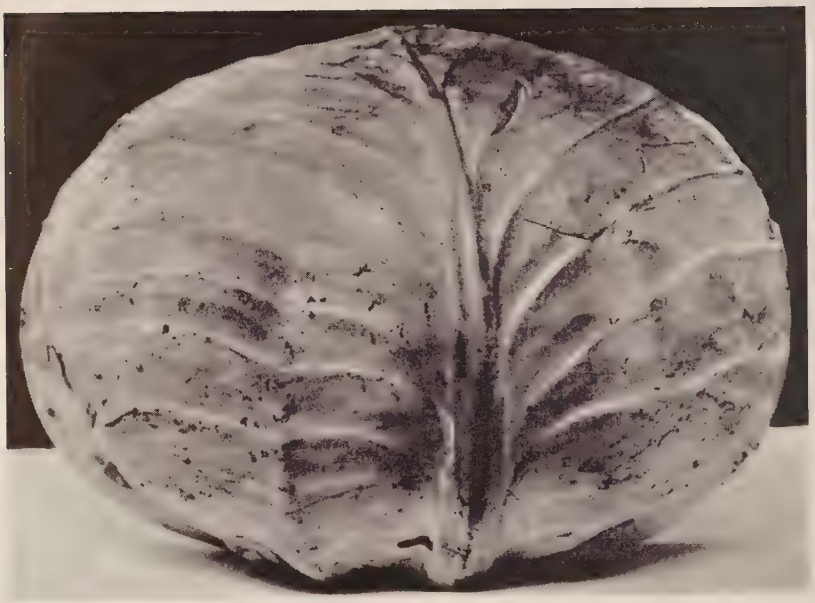

Fig. 44.—A typical head of Penn State Ballhead cabbage, 1925.

Fig. 45.—A head of Penn State Ballhead cabbage, 1941.

of Ballhead, figure 44, but the uniformity and yield of the variety soon largely dispelled this objection. However, because of the objection, it was believed to be of interest to determine whether there is a direct relationship between shape of head and yield. In order to determine this, correlation studies were made for the years 1927, 1936, 1938, and 1940, by Love's methods, *(7)*, table 5.

Table 5.—Correlation of weight and shape of heads of cabbage.

YEAR	NUMBER OF HEADS	CORRELATION COEFFICIENT
1927	1546	.21 ∓ .02
1936	249	.20 ∓ .06
1938	1921	.35 ∓ .02
1940	1111	.25 ∓ .03

It will be observed that there is a slight variation in them as shown by the coefficient of correlation, but the average of all of the determinations, with their standard errors is .25 ∓ .02. According to Chaddock *(1)*, "A coefficient of correlation of less than .3 indicates a low degree of association and doubtful significance." Hence we conclude that there is little if any relationship between head weight and shape. Since head weight determines yield, shape of head is not important factor when yield is the major consideration.

Fig. 46.—An erect, sparsely branched seed plant.

Fig. 47.—A many branched seed plant.

Fig. 48.—A seed plant showing a composite of the central leader and many branched types.

characters were observed, but comparatively little was learned of the mode of their inheritance. They are cited because of their possible interest.

One of the first to attract attention was the shape the plant assumes as it reaches the flowering stage. Two rather distinct types are usually present. These are the rather sparsely branched, erect type with a prominent central leader, figure 46, and the many branched type which does not have the central leader, figure 47. Occasionally plants have been found which are a composite of these two types as shown in figure 48. In most cases a study of these characters with respect to their relative frequency and amount of seed produced might prove interesting. Other characters which have been observed and are waiting further opportunity for more careful study are: early maturing strains; slight tendency of some plants to be fertile when pollinated at full bloom; much crumpled leaves; leaves with spiny margins; leaves with brown margins; fasciated seed stalks of various types including very flat and thin, medium wide and thick, and "cork screw"; long seed pods, thick seed pods, drooping seed pods, twin and double seed pods; open heads, multiple heads; male sterility, probably associated with protruding pistils; slight resistance to worm injury; long, medium, and short stems; and slight pimples on the head leaves which are not due to a pathogenic organism. Most of these have been observed since bud pollination was started and doubtless others will be observed and studied when practicable. They are for the present chiefly of genetic interest, but it is unwise to predict what their economic value may be.

Perhaps the problems which are of immediate economic importance are to develop a strain of Penn State Ballhead resistant to cabbage yellows and to study more carefully the performance and utilization of inbred plant strains in the production of first generation crosses.

SUMMARY

Penn State Ballhead cabbage, a leading American variety, was developed by selection from a single plant chosen in 1912. The history of its development, through 1941, is herewith presented.

Many difficulties were encountered and overcome during the course of the study, but not all of the problems concerned in cabbage breeding were solved.

Various methods were tried for carrying the plants over winter for seed production. The best was to trench in soil. This method is fully described.

Experience with insects and diseases, and the methods used to combat them, are recorded.

The production of cabbage seed under controlled conditions is described with the results obtained given.

Comparisons of linebred and inbred strains with their crosses show the possible use of the latter method to secure increased yields.

The method of comparing substrains and the variability of various characters is discussed.

The importance of tests for more than one year is clearly shown.

Little, if any correlation between shape and weight of head was found.

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